Low-Profile Leaky-Wave Antenna with Monopolar Radiation Pattern Using Composite Right / Left-Handed Transmission Line

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1. Introduction

A radio-on-fiber system has been developed for enabling cellular mobile communication in radio-blind areas, such as highway tunnels and underground shopping malls [1],[2]. A distributed antenna system consisting of coaxial cables and couplers has been specifically designed for use in the aforementioned radio-blind areas [2], [3]. In an in-building antenna distribution system, the antenna is installed on the ceiling, hence a low-profile antenna is preferred. Authors have reported a low-profiled top loaded monopole antenna (TLMA) [4],[5]. When the height of the TLMA is 0.03λ, bandwidth of 17.5 % is achieved. However, when the height of TLMA is less than 0.03λ, impedance matching is not achieved [5]. To overcome this problem, a leaky wave antenna is considered as the low-profile and broadband antenna. The leaky-wave antenna in the metamaterial-based mushroom structure has been proposed for a conical beam antenna application [6],[7]. However, the effective feeding structure has not been developed for broadband impedance matching.

This paper presents characteristics of the leaky wave antenna using composite right/left handed transmission line (CRLH-TL) with mushroom structure. A unit cell using mushroom structure is designed. A centre-feeding structure, for impedance matching of leaky wave antenna, is also designed. Then, 1D low-profiled leaky wave antenna is designed by connecting the feeding structure and CRLH-TL. This antenna has monopolar radiation pattern. Finally, bandwidth and gain characteristics of the leaky wave antenna are investigated.

2. Unit Cell of CRLH-TL and Centre Feed Structure

Figure 1 shows a configuration of unit cell. In the CRLH-TL, mushroom structure is used as main structure. L_L is realized by self-inductance of shorting via, and C_L is realized by gap capacitance. Structural parameters are p = 40 mm, g = 0.2 mm, h = 4.5 mm, r = 3.3 mm, ε_r = 1(air), and this model on the infinite ground plane. Figure 2 shows dispersion diagram of this unit cell. Frequency of zeroth order is 2 GHz, and balance condition is achieved here. In this paper, centre frequency of leaky wave antenna is defined 2 GHz, same as zeroth order frequency of unit cell. Fast wave band is from 1.7 GHz to 2.7 GHz. Figure 3 shows bloch impedance (Z_B) characteristics. Z_B is stabilized about 40 + j40 Ω over fast wave band. Therefore, this structure is considered that it is achieved balance condition. Figure 4 shows configurations of centre feeding structure. There are 3 ports, that port 1 coaxial line which is excited as Z_B (= 40 Ω), and port 2, 3 are set up Z_B (= 40 + j40 Ω) condition. Figure 5 shows S-parameters of feeding structure. Two cases of triangular and pin feed elements are compared. Structural parameters are L_{feed} = 30.4 mm, W_{feed} = 26.5 mm, and h = 4.5 mm. The value of W_{feed} is defined as width of microstrip line at Z_B. When the triangular feed element is used, bandwidth is wider (1 GHz ~ 2.8 GHz) as compared with pin feed element.

3. 1D Centre-Fed Leaky Wave Antenna

Figure 6 shows a configuration of centre-fed 1D leaky wave antenna. In this leaky wave antenna, 10 cells are arranged each side. And, both edges of antenna are terminated in Z_B. S-parameter characteristics are shown in Figure 7. S_{11} is less than -10 dB over the range of 1.7 GHz ~ 2.6 GHz, and S_{21} is less than -10 dB all over the range of bandwidth. From the dispersion characteristic, it is considered that point a, b, and c are LH, zeroth order, and RH band, respectively. Figure 8 shows electric fields of the centre-fed leaky wave antenna. At 1.7 GHz (LH), 2 GHz (zeroth order), and 2.6 GHz (RH), wave is radiated backward, broadside, and forward direction. Figure 9 shows radiation patterns of leaky wave antenna. At all of frequencies, vertical polarization is radiated, and radiation is null at 0°. Maximum gain values of yz / xz plane are 6.4 / 3.7, 6.7 / 11.3, and 6.5 / 3 dBi at 1.7, 2, 2.6 GHz, respectively. These radiation patterns are approximately considered as monopolar patterns. Figure 10 shows transmission characteristics (S_{21}, S_{31}) of leaky wave antenna. This antenna is the symmetric structure, so S_{21} and S_{31} are equivalent each other. From here, cell number is defined as the parameter of N. If N is more than 5, S_{21}, S_{31} is less than -10 dB. However, when N is less than 5, S_{21}, S_{31} is more than -10 dB, and larger. It is considered that antenna length is related to radiation efficiency. From this result, if N is more than 5, more than 90% of the input power is radiated. Therefore, in those cases, the Z_B termination doesn't need to be arranged.

4. Bandwidth and Radiation Characteristics of Leaky Wave Antenna

Figure 11 shows the variations of bandwidth and gain for variable cell numbers. Bandwidth is the range of VSWR ≤ 2, and gain is the maximum value of 2 GHz. At N = 5 ~ 10, the values of bandwidth are saturated about 50 %, that is about maximum value. However, if N ≤ 5, bandwidth is going lower. Gain at 2 GHz is going lower as N is decreasing. Therefore, antenna gain is controllable by its length. In addition, there are shown that variation of non-terminated (open-edge) condition as dashed line. When N ≤ 4, bandwidth is varied more than 28 ~ 38 % by the effect of Z_B termination. And, when N ≤ 6, gain at 2 GHz is more than 1 ~ 4 dBi by the Z_B termination. From these results, if the cell number is small, the antenna is need to be terminated Z_B.

5. Conclusion

This paper presents the characteristics of 1D leaky wave antenna using CRLH-TL. The unit cell of CRLH-TL is designed with mushroom structure, and balance condition is achieved. And, broadband is realized by centre feed structure with triangular feed element. Connecting feed structure and CRLH-TL, 1D centre-fed leaky wave antenna is proposed. This antenna has broadband characteristic and monopolar radiation pattern. Finally, bandwidth and gain characteristics are investigated for variable the number of cells and termination condition.

References

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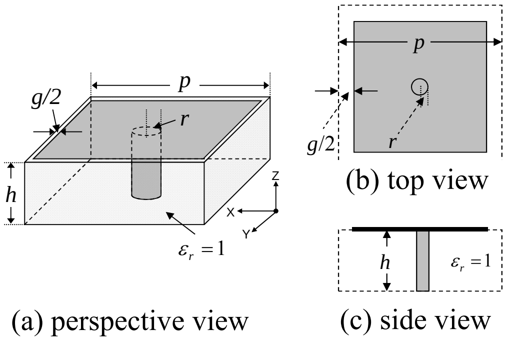


Figure 1: Configuration of unit cell.

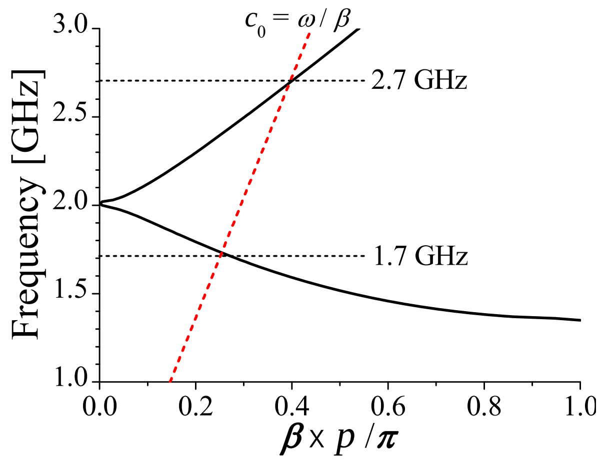


Figure 2: Dispersion diagram.

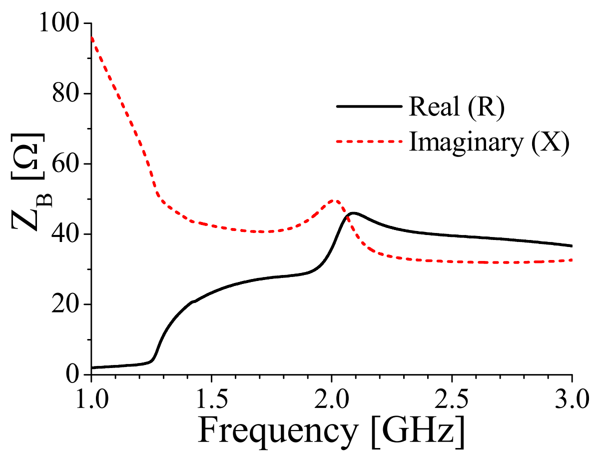


Figure 3: Bloch impedance of unit cell.

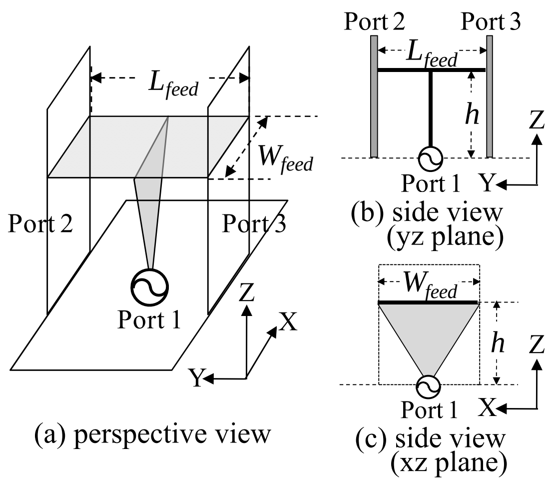


Figure 4: Configuration of feeding structure.

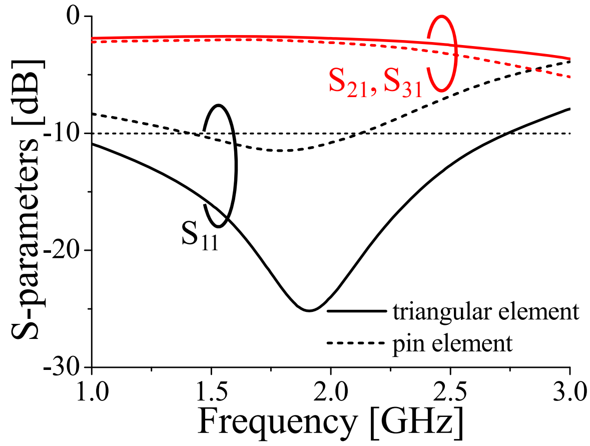


Figure 5: S-parameters of feeding structure.

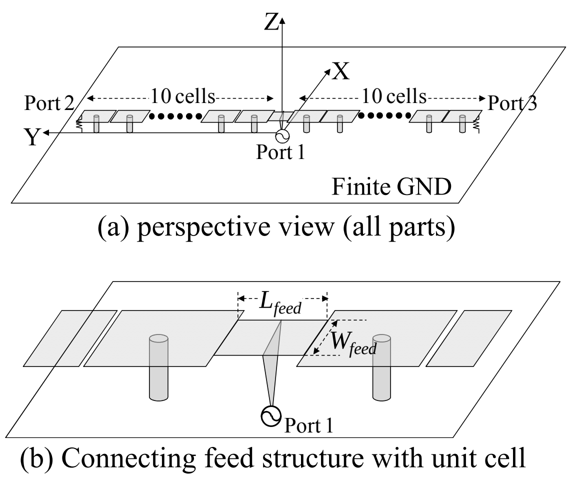


Figure 6: Configuration of leaky wave antenna.

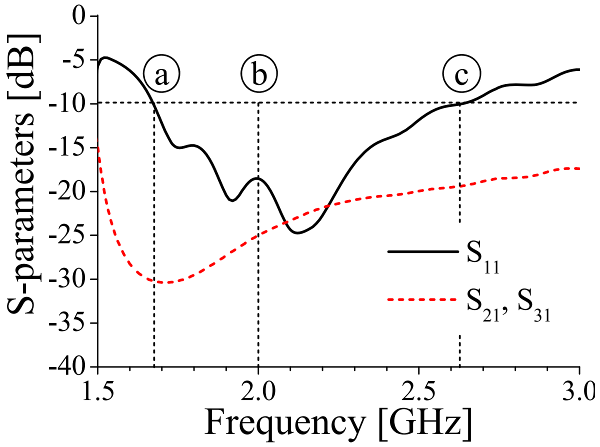


Figure 7: S-parameter characteristics.

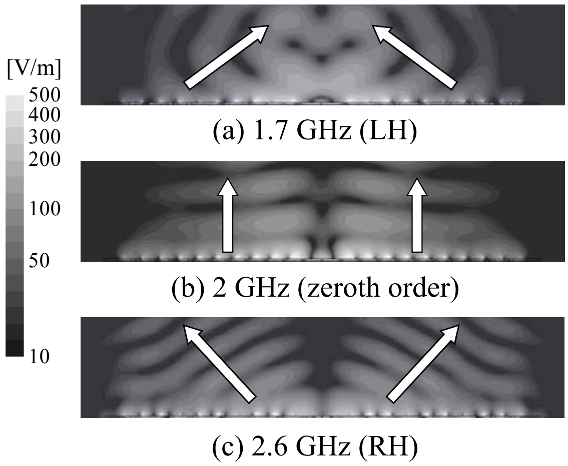
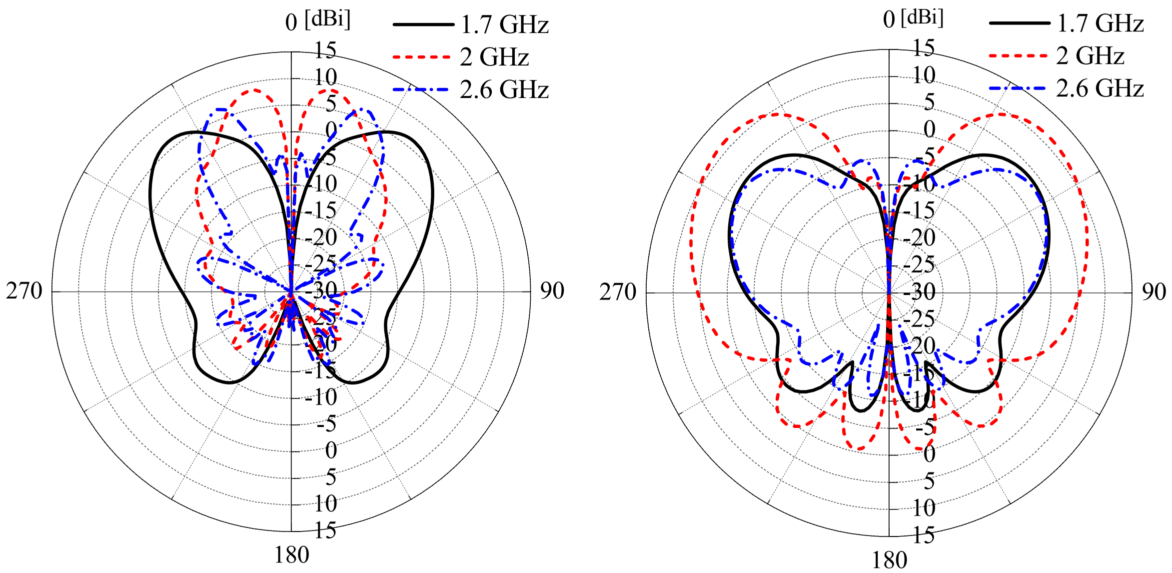


Figure 8: Electric field (yz plane).



(a) yz plane (b) xz plane

Figure 9: Radiation patterns (E_θ).

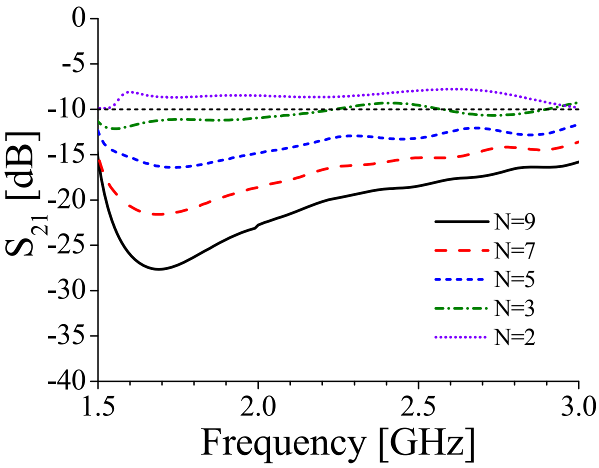


Figure 10: S_{21} characteristics.

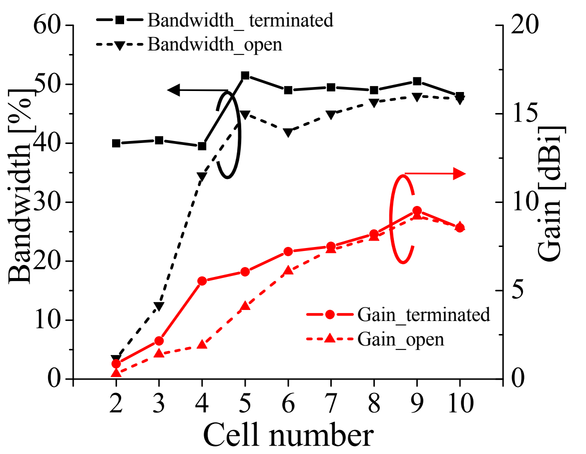


Figure 11: Bandwidth and gain characteristics.